Cluster based Anycast Routing Protocol for Wireless Sensor Networks

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ABSTRACT
Achieving both energy efficiency and scalability at the same time is a challenging task in wireless sensor networks (WSN). In this paper, we describe the mechanism of Cluster Based Anycast Routing protocol (CBAR) for routing in WSN. This is very crucial to ensure that the system operates at minimum energy with increasing scalability and network life-time in WSN. Main objective of this research is to minimize the energy consumption and thereby enhance the scalability and network life-time. The network life-time can be increased with the introduction of the heterogeneity in sensor nodes. Energy consumption is very much dependent upon the efficiency of routing protocols. The design of the protocol aims to satisfy the requirements of sensor networks that every sensor transmits and receives the data as per the requirement of the node and cluster head. In each cluster, Cluster head (CH) is elected among all the clusters depending upon the efficiency of the node and sensing area coverage. CBAR avoids both flooding and periodic updates of routing information but Cluster head get information updates on the failures of nodes and modification in the cluster. Simulation results show that the proposed CBAR protocol improves energy efficiency and results in an extension of life-time for scalable network when compared with other routing protocols in WSN.

Keywords
WSN, energy efficiency, network life-time, scalability, cluster head, clustering algorithm

1. INTRODUCTION
Wireless Sensor Networks (WSN) is an emerging technology that could revolutionize the way wireless network access is provided. WSN consist of hundreds or thousands of small, cheap, battery-driven, spread-out nodes to accomplish a monitoring or control task jointly [1]. In many WSN applications, the deployment of sensor nodes is performed in an ad-hoc fashion without careful planning and engineering. The interconnection of different wireless devices using wireless links exhibits great potentials in addressing different connectivity issues [2]. After deployment, the nodes must be able to autonomously organize themselves into wireless networks. The main objective of WSN is to reliably detect and estimate event features from the collection of information provided by sensor nodes. WSN are characterized with denser levels of sensor node deployment, higher unreliability of sensor nodes and several power, computation and memory constraints. Due to severe energy constraints of large number of densely deployed sensor nodes, it requires a suite of network protocols to implement various network control and management functions such as synchronization, node localization and network security [3]. The growth and evolution of WSN experienced during the last decade has made possible to develop and deploy inexpensive and self-adaptive monitoring systems composed of multi-functional and distributed wireless sensors [1]. In wireless sensor networks, there is usually a sink which gathers data from the battery-powered sensor nodes. Each sensor performs a sensing task to detect specific events, and is responsible for gathering data to return the data to the Sink node or Base Station (BS). A significant difficulty in designing these networks is the battery energy, which limits the life-time and quality of the networks. Good routing protocols have to be designed for the WSN to extend the life-time of sensor networks. However, the proclaimed limitations of sensor networks which are resource constraints including memory storage, computational power, communication bandwidth and energy resources motivate the challenges in designing a routing protocol that fulfills the requirements of sensor networks [1-3].

The placement of the classical sensors and the network topology are predetermining. However, the sensor nodes on the routing path deplete their energy very rapidly due to the use of fixed paths to transfer the sensed data back to the sink. Communication in the sensor network is based on the wireless ad hoc networking technology [4]. If the sensor nodes cannot directly communicate with the sink, some intermediate sensors must forward the data. The sensor nodes used to forward the data packet to the sink directly. However, those sensor nodes consume their battery quickly; so many multi-hop routing protocols have been proposed to forward the data packets back to the sink via other nodes. Hierarchical or cluster-based routing methods are well-known techniques with particular advantages relating to scalability and efficient communication. In a hierarchical architecture, higher-energy nodes can process and send the information, while low-energy nodes perform the sensing close to the target [3]. Sensor nodes use a lot of energy in sending and receiving messages in wireless sensor networks, so hierarchical routing is an efficient way to reduce energy consumption with data aggregation and fusion. Hence, we consider the approach for designing routing protocol based on the specific communication pattern and also robust to the dynamic nature of the sensor networks.

Anycast is a technique used to deliver a packet to one of many hosts. A group of possibly distributed hosts respond to the same address known as anycast address. A packet destined for an anycast address will be delivered to one of the hosts with that address which is close to the source [5]. IPv6 specially defines anycast addressing as an identifier for a set of interfaces [6, 7]. A data packet is intended to be delivered to an anycast address and routed to a nearest node. Nowadays anycast routing is studied in wireless sensor networks widely and it plays a huge role in hierarchical routing in a network of multiple sinks [8]. The Anycast communications becomes quite important in a network with multiple sinks. Anycast can be an important paradigm for a wireless sensor network in terms of resource, robustness and efficiency for replicated service applications. Assuming that the sources and the sinks are distributed in the network uniformly, the sources sending the data packet to the ”nearest” sink around the area in which the events happen can reduce the hops of packets transmitting, so that it saves energy, reduces the cost of router table maintenance and extends the effect of network survival. When a sensor node produces data, it has to send it to any available sink. A sink selection strategy is to choose a sink for each source arbitrarily. This simple strategy is assumed to balance the energy consumption [9].

In this paper we introduce the mechanism of Cluster Based Anycast Routing protocol (CBAR) for routing in WSN. We have studied other energy efficient and related routing protocols used in WSN. This paper shows the design paradigm of CBAR and compared with other existing protocols in WSN. This paper is organized as: section 2 is concentrated on the discussion of related methods where section 3 describes the mechanism of CBAR, section 4 gives the algorithm for the proposed techniques, section 5 with result and discussion and section 6 concludes the paper.

2. RELATED METHODS

A number of routing protocols for WSN have recently being developed to establish different performance metrics like energy efficiency, scalability with the optimization of routing mechanism. Al-Karaki, et al. [3] has classified protocols according to network structure and protocol operation (routing criteria), which is illustrated in Fig. 1. Routing in WSNs is generally divided in two ways: according to the network structure as flat-based, hierarchy-based, and location-based routing, and according to the protocol operation as multipath-based, query-based, and negotiation-based, QoS-based, or coherent-based. This section focuses on hierarchical routing protocols, because hierarchical routing efficiently way to lowers energy consumption within a cluster, performing data aggregation and fusion to reduce the number of messages sent to the BS.

Heinzelman, et al. [10] introduced a hierarchical clustering algorithm for sensor networks, known as Low-Energy Adaptive Clustering Hierarchy (LEACH). LEACH is a cluster-based protocol that applies randomized rotation of the cluster heads to distribute the energy load evenly among the sensor nodes in the network. The operation of LEACH is organized in rounds, each consisting of a set-up phase and a steady-state phase. During the set-up phase, the network is separated into clusters, each with a randomly selected cluster head from nodes in a cluster. During the steady-state phase, the cluster heads gather data from nodes within their clusters respectively, and fuse the data before forwarding them directly to the sink. LEACH provides sensor networks with many good features, such as clustering-based, localized coordination and randomized rotation of cluster-heads, but expends much energy in cluster heads when directly forwarding data packets to the sink.

Lindsey et al. [11] presented an enhanced LEACH protocol. The protocol, Power Efficient Gathering in Sensor Information Systems (PEGASIS), assumes that all nodes have location information about all other nodes, and that each can send data directly to the base station. Hence, the chain of PEGASIS is constructed easily using a greedy algorithm based on LEACH. Each node transmits to and receives from only one of its neighbors. In each round, nodes take turns to be the leader on the chain path to send the aggregated data to the sink. To locate the closest neighbor node in PEGASIS, each node adopts the signal strength to measure the distance of all neighbor nodes. However, the global information of the network known by each sensor node does not scale well and is not easy to obtain. Since a sensor network generates too much data for the end-user to process, it has to aggregate the data.

Energy consumption is one of the most important criterions for the development of autonomous sensor network nodes. To improve efficiency all the sensor network mote designs used duty cycling techniques which means unused motes go to sleep mode with periodic wake up to save power. Battery replacement is not an option for networks with thousands of physically embedded nodes used in technologies to save power such as power-aware computing, energy-aware software or power management radios [12]. The research in WSN has become more and more active and its applications are also extending. However, many of the IPv6 routing lookup algorithms used nowadays cannot adapt to the new requirements of IPv6 and impact the performance of WSN. Hong et al. [13] proposed an improved longest prefix matching routing algorithm based on IPv6. The network prefixes and the destination addresses are transformed into the decimal system and the network prefixes are stored using Scalable Bloom Filter and the destination addresses are stored segmentally to reduce the number of filters. Fast lookup speed is achieved by equitable distribution of the address prefixes. Power Efficient Data Gathering and Aggregation in Wireless Sensor Networks (PEDAP) [14] is based on a minimum spanning tree. PEDAP assumes that the sink knows the locations of all nodes, and that the routing information is calculated by Prim's algorithm with the sink as the root. PEDAP prolongs the lifetime of the last node in the system while providing a good lifetime for the first node. Additionally, sensor nodes transmit the sensed data to the sink via the previously constructed routing path to produce a minimum energy consuming system. Nevertheless, the intermediate nodes consume energy quickly. In the Hierarchy-Based Anycast Routing (HAR) Protocol for Wireless Sensor Networks [15], the sink constructs a hierarchical tree by sending packets (such as CREQ, CREP, CACP, PREQ) to discover each node's own child nodes in turn. HAR avoids both flooding and periodic updating of routing information, but needs to reconstruct the tree when nodes fail or new nodes are added. The drawback of HAR is that it sends and receives too many packets in the network, expending much energy.

3. CBAR: CLUSTER BASED ANYCAST ROUTING

CBAR is a hierarchical routing protocol based on clustering where base stations and root nodes are cluster-heads. In order to distribute the energy dissipation across the WSN of sensor nodes, CBAR elects sufficient number of cluster-heads and rotates randomly which will communicate with other nodes in each cluster in order to minimize dissipation in energy when each node transmits data to cluster-head and receives data from its cluster-head node. If the cluster-head is base station then it will not involve in inter-cluster routing otherwise elected cluster-head nodes will send the data to the base station. The entire protocol is based on two processes or phases where the initial stage concentrates on building the tree and then it will start the routing process. So, the first phase which is called building phase is based on building the topology and election of cluster-heads and the final phase is transmission phase which is based on routing strategies for managing nodes and transmitting data among nodes.

3.1 Building Tree

We consider a network composed of a small number of base stations and a numerous number of wireless sensors randomly distributed where the first phase will design the topology based on the election of cluster-heads and responsible for the formation of clusters with cluster-head and other nodes. The base stations are initially elected as cluster-head and initiate the tree construction by broadcasting a child request (CREQ) to discover the child node. The child nodes send a child reply (CREP) to the required cluster-head for joining the cluster and become the member of the tree. Upon receiving CREP packet, the parent node replies with a child acceptance (CACP) packet. So, finally the ACK packet from child to parent in reply to the CACP packet completes the binding in the cluster. In this network all sensor nodes have limited processing power, storage, bandwidth and energy but base stations have powerful resources and hence required to initiate the process to perform any task or communicate with the sensors. Let BS and N be the set of base stations and number of sensor nodes respectively. Accordingly to area coverage of base stations, clusters are formed but simultaneously some nodes in each region are also elected as cluster-head depends upon the decision made by the election process and the nodes which are static in nature with better area coverage and resources. The election algorithm selects the node on the value generated by the performance of the node as the overhead of cluster-head is higher than other nodes. Then each elected cluster-head broadcasts an advertisement message to the rest of the nodes in the network to join their clusters. Based upon the strength of the CREQ signal, nodes send CREP packet to join the cluster. Whenever any node moves from one region to another region it will join the cluster accordingly and send information to the respective cluster-head. In this protocol the tree formation is hierarchical where base stations (BS) are connected to cluster-heads (CH) and each cluster-head connects to nodes in the cluster for the formation of the tree structure. These procedures are performed by every node throughout the network to complete the tree formation.

3.2 Clustering

Before routing first work to elect cluster-heads from each cluster for the sensor network depending on the election algorithm which may vary for every round of election. Each cluster in the network has unique cluster id. Then data will be transmitted from nodes to the respective cluster-head (CH) and these cluster head takes part in data transmission and finally transmits it to sink. Rest other nodes in each cluster are in sleep mode to conserve energy. As only cluster heads takes part in routing of data from source to sink, each node in the cluster sends all its data to cluster-head in each round. The weighted sum method is also used for determining the routing conditions. Various considerations are followed in the proposed the network model and sensor nodes.

1. The sink and source are placed at opposite ends
2. The sensor nodes are randomly deployed in cluster
3. All nodes are of same types of sensor node
4. Data need to be collected together for sending it to cluster-head

The election of a CH among the fellow nodes for a cycle is based on battery power and the distance from the sink of each node.

As cluster heads takes part in routing so the energy must be efficiently used by them. Once the cluster heads are formed other nodes goes to sleep, as they do not take part in routing so, as to conserve energy. After one round again the same selection process is being executed for a new cluster head. Usually the battery assigned to each node is being consumed with every action of transmission or sleeping but the one with the highest value and distance from the sink gets the chance to be a cluster head, as the weighted sum method is employed giving more weight age to battery power over distance, the actual election process is being executed keeping in mind the criteria of energy efficiency. Weighted sum is the method for solving optimization which seeks solution by systematically varying weights among the objective conditions under given constraints this is the way to achieve high performance. The weights are assigned to the battery and distance from the sink, as keeping in mind the equation they must satisfy;

$$\Sigma W_i J_i = 1 \text{ and } W_1 J_1 + W_2 J_2 = 1 \qquad (1)$$

Where, $W_1 = W_b$ is the weight given to the battery of the node and $W_2 = W_d$ is the weight given to the distance; J_i is the quantity multiplied to the weights of i-th factor

Scheduling policy is used to find out how to forward the packet from source to destination. Sleep Wake up scheduling is used to find out when the nodes are wake-up. This sleep wake up scheduling is used to increase the lifetime of sensor nodes .Asynchronous sleep wake up each node wake up independently of neighboring nodes in order to save energy. This approach is responsible uniquely balancing the work between the nodes according to set conditions that effectively result in the formation of a node that is much stronger among others in terms of battery and distance. In CBAR sensors are organized into clusters and one node in each cluster acting as cluster-head takes the responsibility to collect data, aggregate data and finally transmit data to the distant Sink. Lifetime of heterogeneous wireless sensor networks can be increased in networks with more than one data sink when access to the sinks is provided by an Anycast protocol [9]. Such a network consists of two types of devices resource rich (information sinks) and resource-constrained (sensors generating new data) shown in Fig. 2. A similar concept of improving the energy efficiency of WSNs has been proposed in the HAR protocol [15]. In the view of the Anycast routing protocol in wireless sensor network, combining the characteristics of wireless sensor networks and to improve the performance of Anycast routing, this paper puts forward a method which based on the Anycast tree routing algorithm for wireless sensor networks.

3.3 Data Dissemination Phase (DDP)

Sensor nodes can start disseminating the sensed data to the sink via the parent node. The packet format is as follows: (Seq_No, Source_ID, Dest_ID, Sink_ID, Data_Length, Payload). The Seq_No field is the sequence number of the packet and Source_ID, Dest_ID, Sink_ID fields respectively is the source node of the packet, the destination node of the packet, the sink node that requests the data packet. The Data_Length field denotes the packet length and the payload field is used to carry the data. A receiver acknowledgement packet is sent when the data packet is successfully transmitted to the parent node. The parent node then replies with this packet to notice the source node and forwards the data packet to the next hop. Each node performs the same until the data packets send to sink node via cluster-head. The data packet can be forwarded to the sink via many paths. The life-time of the network system can be extended if the sensor node always uses a different path to send data packets.

3.4 Network Layer Maintenance

A Network Layer Maintenance described in this section is used to reconstruct the tree if some internal nodes have failed due to numerous reasons. For instance, the battery of the node is depleted with the time, or the node can be damaged due to harsh environment or by the enemy. The tree in CBAR is self-organized and it is reconstructed on-demand, i.e., whenever the nodes have data to send. A detection of such failed nodes relies on the underlying MAC layer protocol. A newly deployed node finds a parent by using a joining mechanism as follows. A joining node broadcasts a parent request (PREQ) packet making the neighboring nodes aware of its existence. Any members of the tree that hear this packet reply by unicasting a CREQ packet to the joining node. Note that this CREQ packet is same as described in Section 3.1 except that we use unicasting instead of broadcasting. Then, the processes will follow the tree construction phase, i.e., the joining node sends a CREP packet to a selected parent and waits for a CACP packet as a confirmation of their relation. If the joining node does not receive any CREQ packet after broadcasting the PREQ packet, it infers that no any node is within its radio coverage or all of its neighboring nodes do not attach to the tree yet. In this case, it waits for an incoming CREQ packet after one of its neighbors has attached to the tree. As an option, joining node can broadcast the PREQ packet periodically until receiving the CREQ packets.

3.5 Anycast Routing

When the network size becomes larger, it is impossible to use only one base station even though we have an optimal routing protocol because the traffic will concentrate around the base station incurring high loss rate. Thus, the user can deploy the base stations at some ratio compared to the number of sensors in order to distribute the loads. Multiple base stations can operate independently without any change in our protocol. Each node should attach to the tree created by a potential nearest base station because a CREQ packet from such base station should arrive first. The nodes can use the group ID to distinguish different base stations. Thereby, they can attach to multiple trees in order to achieve the robustness against failed nodes, i.e., multipath routing is supported. To collect the data, each node just forwards its sensed data and all of received data to its parent. If it does not attach to the tree yet, it keeps such data in the buffer and send them later.

4. CBAR ALGORITHM

The algorithm is explained in the following steps:

Step 1: Initialization

Set number of CREP = 0 and status of parent node, CREP send and received, CREQ send and receive as NULL.

Choose BS as parent (node), BS broadcasts CREQ packets, Sensor broadcasts PREQ packets, call election algorithm to select cluster-head (CH).

Step 2: Formation of tree

Select cluster-head (CH) near the sink (BS) and if node elected as CH connect to BS and send request to nodes else node will join CH as leaf in the tree as source node

Step 3: Topology model

- All sensor nodes are started with same initial energy with transmission distance d_0
- Each sensor node can compute the distance d of the source based on the received location information
- Transmitting power of a sensor node is controllable, i.e., transmitting power of a sensor node can be modulated according to the transmitting distance
- Change the flag values accordingly as per transmission and buffer the packets for transmission

Step 4: Update energy of each sensor node

The transmission depends on the energy of the node and distance between CH and BS with nodes depending on the following factor on a weighted basis.

$$T_c = W_1 * D + W_2 * E_f \qquad (2)$$

where T_c is transmission criterion, W_1 and W_2 are the weight factors; D is the proximity factor on the given distances of the node with BS and CH whose T_c will be calculated.

The energy dissipated during transmission and reception using the following formula:

$$E_{T_X}(k,d) = \begin{cases} E_{elec} * k + \xi_{fs} * k * d^2, & d < d_0 \\ E_{elec} * k + \xi_{mp} * d^4, & d \geq d_0 \end{cases}$$

$$E_{R_x}(k,d) = E_{elec} * k \qquad (3)$$

where E_{Tx} is the amount of energy consumed by each node, E_{Rx} is the amount of energy for receiving k bit packet, E_{elec} is the energy dissipated, ξf_s is the free space propagation, ξ_{mp} is the multiple fading channel parameter, d is the transmission distance and k is message length and d_0 is the initial value of d.

Step 5: Each node transmit data during their allocated time slot t and finally data will be transmitted to BS via CH

A simple combination of different routing metrics [9] used to determine the path cost using following equations:

$$\phi = \phi' + \Sigma\, \alpha_i * metric_i \qquad (4)$$

$$\phi = \phi' + \alpha_1 * hop_i + \alpha_2 * w_i + \alpha_3 * delay + \alpha_4 * E_i$$

Where ϕ' is the accumulated cost along the path with different path cost metrics, $metric_i$ is scaled value from (0, 1) and α_1 is the weight factor for $metric_i$ to calculate the cost. Here, hop_i is hop count set to 1 initially, E_i denotes the surplus energy, α_i values are different sets of weight factors set as per requirements as per applications. w_i is calculated as per the energy consumption of node i and calculated as per following:

$$w_i = e_s + e_g + e_r + e_{ij}$$

where e_{ij} calculated as per the power consumption of node i transmitting data to node j where e_g is the value of generating data, e_r is the value of receiving data and e_s is the value of idle power consumption of node.

Step 6: After completion of one round repeat step 2 to 5

Step 7: Stop

Each time after selection of cluster-heads (CH) the information will broadcast in the cluster so that each node can send PREQ to establish connection with CH but in CBAR the broadcast process will be once to minimize the overhead and utilize less energy. CBAR also reduce the overhead by minimizing the hop in routing and avoid periodic update to reduce the traffic in the network.

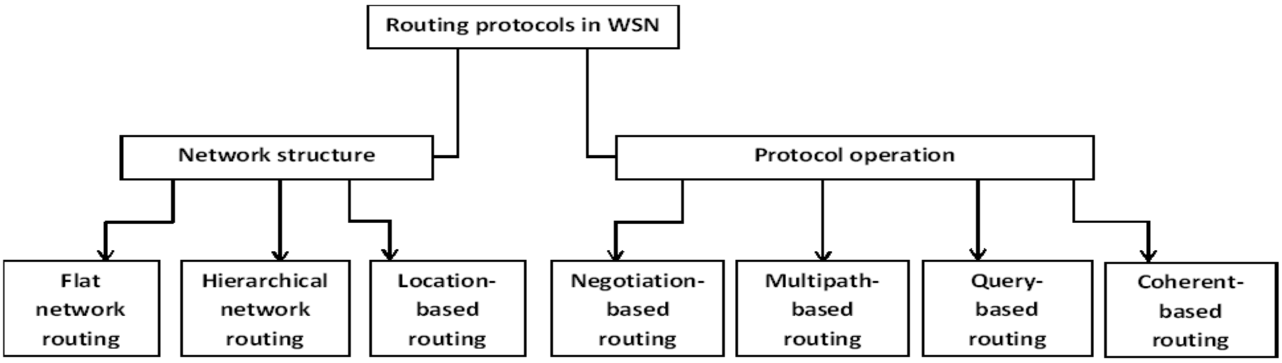

Fig. 1: Routing Protocols in WSN

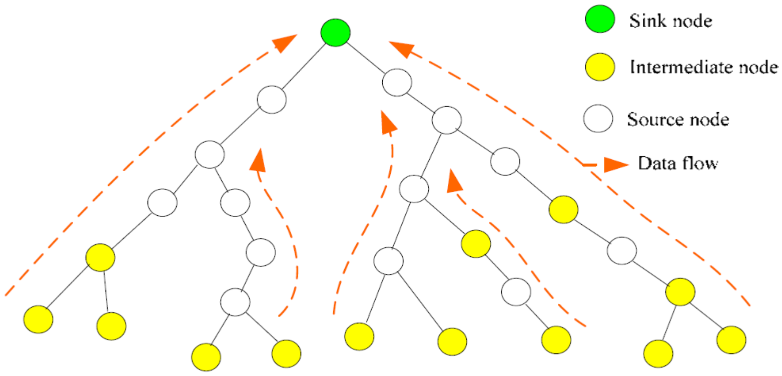

Fig. 2: an anycast tree established from all sensor nodes to a sink

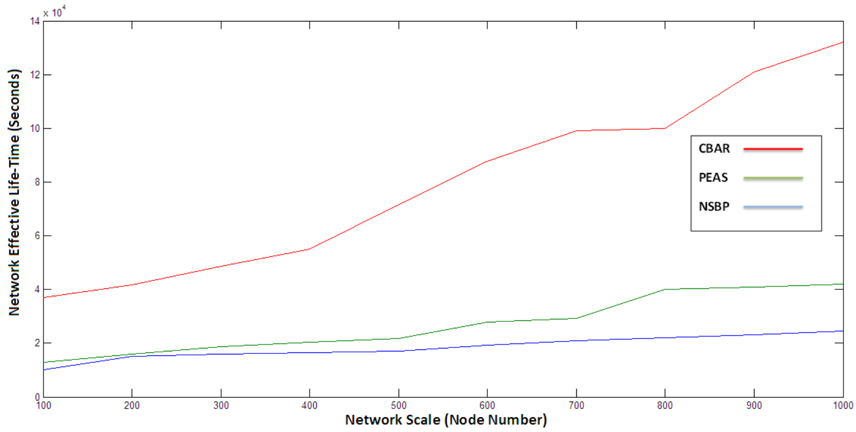

Fig. 3: Network Effective Lifetime vs. Network Scale

5. SIMULATION RESULTS

In this section cluster based anycast routing (CBAR) routing protocol is evaluated and compared it with other available schemes. Assume that there are 100 sensor nodes distributed randomly in 100x100 regions. The simulation parameters are given in Table 1.

CBAR compared with modified LEACH, HAR, Node Scheduling based Routing protocols, GAF, PEAS, NSBP protocol. Network effective lifetime states that the data efficiently can be transmitted back to sink. This is calculated for the network scale of 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 nodes shown in horizontal direction.

Fig. 3 shows the performance of CBAR compared with NSBP, PEAS and for comparison between the effective lifetimes, Nodes death time and effective lifetime compared taking scale of 1000 nodes. Fig. 4 shows the performance of the nodes in terms of number of sensor nodes alive per round which has not yet depleted all the energy and still involve in data dissemination and Fig. 5 shows the energy consumption of the nodes after each round and it increases as number of packet transfer also increase with time.

Table 1. The parameters used in the simulation

Parameters	Value	Parameters	Value
Size of target area	100 x 100 m^2	Data packet size	512 bytes
No. of sink nodes	5	Metadata packet size	25 bytes
No. of sensor nodes	95	Maximum radius, R	20m
Initial Energy	10 J	α_1	1
Transmitting energy	50 nJ/bit/m^2	α_2	1
ξ_{elec}	50 nJ/bit	α_3	1
e_s	100 nJ/s	α_4	1

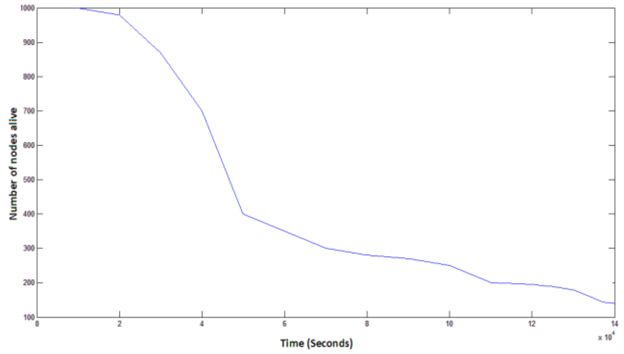

Fig. 4: Number of nodes alive after each round

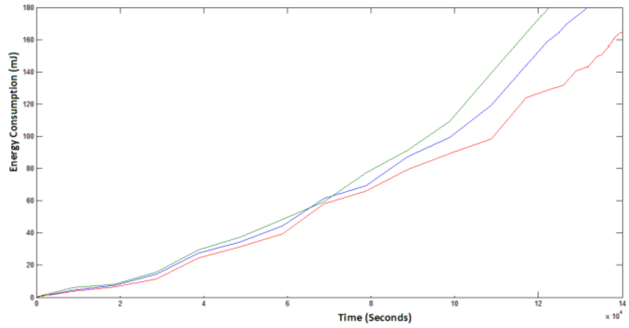

Fig. 5: Energy consumption after each round

6. CONCLUSION

Energy is one of the major parameter in Wireless Sensor Networks. Routing consumes the largest amount of energy in WSN for routing and in terms of achieving efficient routing mechanism for collecting data packets. Lots of redundant information is available in WSN due to widely deployed nodes but anycast mechanism is limited to cluters and the approaches are different for both inter-cluster and intra-cluster communication due to the pre-defined role of cluster head. This paper has demonstrated the routing strategy of CBAR protocol and showed how it provides the solution against the dynamic natures of WSN. It also tries to overcome the shortcoming of other protocols in terms of scalability for enhancing network life-time. However, we have not explored all required performance matrices which is one of our future work.

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